APPENDIX A. RELATED REGULATIONS AND DOCUMENTS

A.1 Regulations.

Table A.1 shows the regulations related to icing certification for 14 CFR parts 23, 25, 27, and 29 aircraft. Table A.2 shows the regulations for certification of engines with regard to icing. Table A.3 shows the airworthiness regulations for propellers and Table A.4 shows the operating rules.

Table A.1. Related 14 CFR Parts 23, 25, 27, and 29 Regulations

Subpart	Part 23 - Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes	Part 25 - Airworthiness Standards: Transport Category Airplanes	Part 27 – Airworthiness Standards: Normal Category Rotorcraft	Part 29 – Airworthiness Standards: Transport Category Rotorcraft
B-Flight	§ 23.49 Stalling period § 23.65 Climb: All engines operating § 23.67(e)(2) Climb: One-engine inoperative § 23.67(e)(3) Climb: One-engine inoperative § 23.71 Glide: Single-engine airplanes § 23.75 Landing Distance § 23.77 Balked landing § 23.143 General—Controllability and Maneuverability § 23.171 General – Stability § 23.201 Wing level stall § 23.203 Turning flight and accelerated turning stalls § 23.207 Stall warning § 23.251 Vibration and buffeting	§ 25.103 Stalling speed § 25.117 Climb: general § 25.119 Landing Climb: All-engines-operating § 25.121 Climb: One-engine-inoperative § 25.123 En route flight paths § 25.125 Landing § 25.143 General—Controllability and Maneuverability § 25.171 General – Stability § 25.201 Stall demonstration § 25.203 Stall characteristics § 25.207 Stall warning § 25.237 Wind velocities § 25.251 Vibration and buffeting § 25.253 High-speed characteristics	§ 27.65 Climb: all engines operating § 27.67 Climb: one engine inoperative § 27.71 Glide performance § 27.73 Performance at minimum operating speed § 27.75 Landing § 27.79 Limiting height-speed envelope § 27.141 General—Flight Characteristics	§ 29.45 General—Performance § 29.49 Performance at minimum operating speed § 29.51 Takeoff data: general § 29.64 Climb: General § 29.71 Helicopter angle of glide: Category B § 29.75 Landing: General § 29.87 Height-velocity envelope § 29.141 General—Flight Characteristics

Subpart	Part 23 - Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes	Part 25 - Airworthiness Standards: Transport Category Airplanes	Part 27 – Airworthiness Standards: Normal Category Rotorcraft	Part 29 – Airworthiness Standards: Transport Category Rotorcraft
D-Design and Construction	§ 23.601 General § 23.603 Materials and workmanship § 23.605 Fabrication methods § 23.607 Fasteners § 23.609 Protection of structure § 23.611 Accessibility provisions § 23.613 Material strength properties and design values § 23.629 Flutter § 23.773 Pilot compartment view § 23.775(f) Windshields and windows § 23.775(g) § 23.863 Flammable fluid fire protection	§ 25.601 General § 25.603 Materials § 25.605 Fabrication methods § 25.607 Fasteners § 25.609 Protection of structure § 25.611 Accessibility provisions § 25.613 Material strength properties and design values § 25.629 Aeroelastic stability requirements § 25.773(b)(1)(ii) Pilot compartment view § 25.775(d) Windshields and windows § 25.875 Rei nforcement near propellers	§ 27.601 General § 27.603 Materials § 27.605 Fabrication methods § 27.607 Fasteners § 27.609 Protection of structure § 27.611 Inspection provisions § 27.613 Material strength properties and design values § 27.629 Flutter	§ 29.601 General § 29.603 Materials § 29.605 Fabrication methods § 29.607 Fasteners § 29.609 Protection of structure § 29.611 Inspection provisions § 29.613 Material strength properties and design values § 29.629 Flutter and divergence § 29.773(b)(1)(ii) Pilot compartment view
E-Powerplant	§ 23.901(d)(2) Installation § 23.903 Engines § 23.905(e) Propellers § 23.929 Engine installation ice protection § 23.939 Powerplant operating characteristics § 23.951(c) Fuel System, General § 23.975 Fuel tank vents and carburetor vapor vents § 23.997(e) Fuel strainer or filter § 23.1041 General - cooling § 23.1093 Induction system icing protection § 23.1099 Carburetor deicing fluid system detail design § 23.1101 Carburetor air preheat design § 23.1105 Induction system screens § 23.1157 Carburetor air temperature controls § 23.1189 Shutoff means § 23.1199(b) Extinguishing agent containers	§ 25.901(c) Installation § 25.903 Engines § 25.929 Propeller deicing § 25.939 Turbine engine operating characteristics § 25.941 Inlet, engine and exhaust compatibility § 25.951(c) Fuel System, General § 25.975 Fuel tank vents and carburetor vapor vents § 25.981 § 25.1041 General - cooling § 25.1093 Induction system icing protection § 25.1101 Carburetor air preheat design § 25.1105 Induction system screens § 25.1157 Carburetor air temperature controls § 25.1189 Shutoff means	§ 27.939 Turbine engine operating characteristic s § 27.951(c) Fuel System, General § 27.975 Fuel Tank Vents § 27.1041 General - cooling § 27.1093 Induction system icing protection	§ 29.901(c) Installation § 29.939 Turbine engine operating characteristic s § 29.951(c) Fuel Systems, General § 29.975 Fuel Tank Vents and Carburetor Vapor Vents § 29.1041 General - cooling § 29.1093 Induction system icing protection § 29.1101 Carburetor air preheater design § 27.1105 Induction system screens § 29.1157 Carburetor air temperature controls § 29.1189(a) Shutoff means
F-Equipment	§ 23.1301 Function and installations § 23.1305(c)(7) Powerplant instruments § 23.1307(c) Miscellaneous	§ 25.1301 Function and installation § 25.1305(c)(5) Powerplant instruments	§ 27.1301 Function and installation § 27.1305(p) Powerplant instrumentati on	§ 29.1301 Function and installation § 29.1305(a)(17) Po werplant

Subpart	Part 23 - Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes	Part 25 - Airworthiness Standards: Transport Category Airplanes	Part 27 – Airworthiness Standards: Normal Category Rotorcraft	Part 29 – Airworthiness Standards: Transport Category Rotorcraft
	equipment § 23.1309 Equipment, systems, and installations § 23.1323(e) Airspeed indicating system § 23.1325 Static pressure system § 23.1326 Pitot heat indication systems § 23.1327 Magnetic direction indicator § 23.1351 General § 23.1357 Circuit protective devices § 23.1416 Pneumatic de-ice boot system § 23.1419 Ice protection	§ 25.1309 Equipment, systems, and installations § 25.1323(e) Airspeed indicating system § 25.1325(b) Static pressure systems § 25.1326 Pitot heat indication system § 25.1327 Magnetic direction indicator § 25.1351 General § 25.1357 Circuit protective devices § 25.1403 Wing icing detection lights § 25.1419 Ice protection	§ 27.1309 Equipment, systems, and installation § 27.1325(b) Static pressure systems § 27.1419 Ice protection	instruments § 29.1309 Equipment, systems, and installations § 29.1323(f) Airspeed indicating systems § 29.1325(c) Static pressure and pressure altimeter systems § 29.1419 Ice protection
G-Operating Limitations and Information	§ 23.1525 Kinds of operations § 23.1529 Instructions for Continued Airworthiness § 23.1559(b) Operating limitations placard § 23.1583(h) Operating limitations § 23.1585 Operating procedures	§ 25.1525 Kinds of operations § 25.1529 Instructions for Continued Airworthiness § 25.1583 Operating limitations § 25.1585(a)(6) Operating procedures	§ 27.1525 Kinds of operations § 27.1529 Instructions for Continued Airworthiness § 27.1559 Limitations placard § 27.1583 Operating limitations § 27.1585 Operating procedures	§ 29.1525 Kinds of operations § 29.1529 Instructions for Continued Airworthiness § 29.1559 Limitations placard § 29.1583 Operating limitations § 29.1585 Operating procedures
Other		Appendix C		Appendix C To Part 29-Icing Certification

Table A.2. Related 14 CFR Part 33 - Airworthiness Standards: Aircraft Engines Regulations

Subpart		
A - General	§ 33.4	Instructions for Continued Airworthiness
E - Design and Construction; Turbine Aircraft Engines	§ 33.65	Foreign object ingestion–ice
	§ 33.66	Bleed air system
	§ 33.67(b)(4)(ii)	Fuel system
	§ 33.68	Induction system icing
	§ 33.77	Foreign object ingestion - ice
	§ 33.89(b)	Operational test

Table A.3. Related 14 CFR Part 35 - Airworthiness Standards: Propellers

Subpart		
A - General	§ 35.3	Instruction manual for installing and operating the propeller
	§ 35.4	Instructions for Continued Airworthiness

Table A.4. Related Operating Rules

Subchapter	14 CFR Part	Subpart	Section
F – Air Traffic and General Operating Rules	91, General Operating and Flight Rules	F – Large and Turbine-Powered Multiengine Airplanes	§ 91.527 Operating in icing conditions
G – Air Carriers and Operators for Compensation or Hire: Certification and Operation	121, Operating Requirements; Domestic, Flag, and Supplemental Operations	U – Dispatching and Flight Release Rules	§ 121.629 Operating in icing conditions
	125, Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Maximum Payload Capacity of 6,000 Pounds or More; and Rules Governing Person On Board Such Aircraft	F – Instrument and Equipment Requirements	§125.221 Icing conditions: Operating limitations
	135 - Operating Requirements: Commuter and On Demand Operations and Rules Governing Person On Board Such Aircraft	D – VFR/IFR Operating Limitations and Weather Requirements	§ 135.227 Icing conditions: Operating limitations

14 CFR SFAR No. 88 Fuel Tank System Fault Tolerance Evaluation Requirements

A.2 Advisory Circulars

ACs listed below may be available on the FAA web site. The ACs may also be obtained from the U.S. Department of Transportation, Subsequent Distribution Office, SVC-121.23, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785:

AC 20-xx Turbojet, Turboprop, and Turbofan Engine Induction System Icing

AC 20-115B Radio Technical Commission for Aeronautics, Inc. (RTCA) Document RTCA/DO-178B

AC 20-117A Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing.

AC 21-16D RTCA Document DO- 160D

AC 21-40 Application Guide for Obtaining a Supplemental Type Certification

AC 23-17A Systems And Equipment Guide For Certification Of Part 23 Airplanes

AC 23.143-1 Ice Contaminated Tailplane Stall

AC 23.629-1A	Means of Compliance with Section 23.629, Flutter.
AC 23.1309-1C	Equipment, Systems, and Installation in Part 23 Airplanes
AC 23.1419-2B	Certification of Part 23 Airplanes for Flight in Icing Conditions
AC 25-11	Transport Category Airplane Electronic Display Systems
AC 25-22	Certification of Transport Airplane Mechanical Systems
AC 25.629-1A	Flutter Substantiation of Transport Category Airplanes
AC 25.1309-1A	System Design Analysis
AC 25.1419-1	Certification of Transport Category Airplanes for Flight in Icing Conditions
AC 27-1B	Certification of Normal Category Rotorcraft
AC 29-2C	Certification of Transport Category Rotorcraft
AC 33-2B	Aircraft Engine Type Certification Handbook
AC 120-42A	Extended Range Operation with Twin-Engine Airplanes (ETOPS)
AC 120-58	Pilot Guide for Large Aircraft Ground Icing
AC 120-60	Ground Deicing and Anti-Icing Program
AC 135-16	Ground Deicing & Anti-icing Training & Checking
AC 135-17	Pilot Guide - Small Aircraft Ground Deicing (pocket)

Note: The AC listed below is available from the Superintendent of Documents, U.S. Government Printing Office, Washington D.C. (stock number 050-007-01214-4, $33.00).

AC 25-7A, Change 1 Flight Test Guide for Certification of Transport Category Airplanes

Copies of the current editions of the following ACs may be purchased from the Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954. Make check or money order payable to the Superintendent of Documents:

AC 23-8A and AC 23-8A, Change 1 Flight Test Guide for Certification of Part 23 Airplanes.

A.3 Related Reading Material

(1) FAA Technical Report DOT/FAA/CT-88/8-1, “Aircraft Icing Handbook,” published March 1991, updated September 1993, includes reference material on ground and airborne icing facilities, simulation procedures, and analytical techniques. This document represents all types and classes of aircraft and is intended as a working tool for the designer and analyst of IPSs. The FAA Technical Center continues with the transfer of material from the Aircraft Icing Handbook (AIHB) to the Electronic Aircraft Icing Handbook (EAIHB) web site:

http://www/fire.tc.faa.gov/aar421/eaihbpg.html

(2) FAA Technical Report ADS-4, "Engineering Summary of Airframe Icing Technical Data," and Report No. FAA-RD-77-76, "Engineering Summary of Powerplant Icing Technical Data," provide technical information on airframe and engine icing conditions, and methods of detecting, preventing, and removing ice accretion on airframes and engines in flight. Although most of the information contained in ADS-4 and FAA-RD-77-76 is still valid, some is outdated. More usable information is now available through recent research and experience and is included in the Aircraft Icing Handbook referenced in paragraph (1) above.

Note: The FAA technical reports listed above can be obtained from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

(3) NACA Technical Note 1855 (1949), "Recommended Values of Meteorological Factors To Be Considered in the Design of Aircraft Ice-Prevention Equipment," NASA Ames Research Center, Moffett Field, California 94035.

(4) NACA Technical Note 2738 (1952), "A Probability Analysis of the Meteorological Factors Conducive to Aircraft Icing in the United States," NASA Glenn Research Center, Cleveland, Ohio 44135.

(5) RTCA/DO160D, "Environmental Conditions and Test Procedures for Airborne Equipment."

(6) RTCA/DO-178B, "Software Considerations in Airborne Systems and Equipment Certification," published December 1, 1992, provides an acceptable means of compliance for software used in airborne systems and equipment. This document may be obtained from the RTCA Inc., 1140 Connecticut Avenue NW, Suite 1020, Washington, D.C. 20036.

(7) RTCA/DO-254, "Design Assurance Guidance for Airborne Electronic Hardware."

Note: These documents may be obtained from the RTCA Inc., 1140 Connecticut Avenue NW, Suite 1020, Washington, D.C. 20036.

(8) SAE AIR5504, "Aircraft Inflight Icing Terminology," (publication pending).

(9) SAE AIR1168/4, "Ice, Rain, Fog, and Frost Protection."

(10) SAE ARP4087, "Wing Inspection Lights – Design Criteria."

(11) SAE ARP4754, "Certification Considerations for Highly-Integrated or Complex Aircraft Systems."

(12) SAE ARP4761, "Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment."

(13) SAE ARP5903, "Droplet Impingement and Ice Accretion Computer Codes," (publication pending).

(14) SAE ARP5904, "Airborne Icing Tankers," (publication pending).

(15) SAE ARP5905, "Calibration and Acceptance of Icing Wind Tunnels," (publication pending).

Note: The above SAE Aerospace Recommended Practices documents can be obtained from the SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

APPENDIX B. NOMENCLATURE

B.1 Terms

Anti-icing: The prevention of ice formation or accumulation on a protection surface, either by evaporating the impinging water or by allowing it to run back and off the surface or freeze on non-critical areas.

Appendix C: The 14 CFR parts 25 and 29, Appendix C icing envelopes for continuous maximum and intermittent maximum icing conditions.

Appendix C icing conditions: 14 CFR parts 25 and 29 Appendix C certification icing condition standard for approving ice protection provisions on aircraft. The conditions are specified in terms of altitude, temperature, liquid water content (LWC), representative droplet size (mean effective diameter [MED]), and cloud horizontal extent. (Note: in Appendix C, the term "mean effective diameter" refers to what is now called the "median volume diameter (MVD)," determined using rotating multi-cylinders and assuming a Langmuir distribution.)

Artificial ice: Ice formed by artificial means, such as a spray rig in a wind tunnel or on a tanker.

Clear ice: See "glaze ice."

Collateral Icing: Ice accretions that occur on aircraft surfaces other than those typically considered when aircraft are tested for certification using simulated ice shapes. Examples are ice feathers that accumulate on fuselage, nacelle, nacelle pylons, empennage, antennas, and wing surfaces.

Collection efficiency: See "water catch efficiency."

Computational fluid dynamics (CFD): The science of solving discretized equations for fluid flow on a computer.

Computed ice: An ice shape generated by computational fluid dynamic (CFD) codes or other analytical means.

Critical ice shape: The aircraft surface ice shape formed within required icing conditions that results in the most adverse effects for specific flight safety requirements. For an aircraft surface, the critical ice shape may differ for different flight safety requirements, e.g., stall speed, climb, aircraft controllability, control surface movement, control forces, air data system performance, dynamic pressure probes for control force "feel" adjustment, ingestion and structural damage from shed ice, engine thrust, engine control, and aeroelastic stability.

Critical Aircraft Ice Shape Configuration: The ice-contaminated aircraft configuration (including ice accretions on all accreting surfaces) that results in the most adverse effects for specific flight safety requirements.

Critical surface: A surface whose integrity affects safe flight and landing of an aircraft. A surface that accretes ice and affects safe flight and landing of an aircraft is a critical surface relative to inflight icing.

Deice or Deicing: The periodic shedding or removal of ice accumulations from a surface, by destroying the bond between the ice and the protection surface.

Empirical validation/evaluation: Validation or evaluation of analytical results by means of experimental data.

Euler Equations: The title given to equations, developed by L. Euler, of motion for flow of a frictionless, non-viscous fluid. The equations address compressibility of a fluid, but do not address flowfield discontinuities, such as those from shocks. When used to calculate flow along streamlines, the rotation of the flow field can be computed. The Euler equations of fluid flow can be integrated throughout a finite region to determine the dynamic equilibrium of a finite volume of particles, applying Newton's second law (momentum) to the group of fluid particles. This flowfield solution is called Eulerian, as compared with a more complex flowfield solution that tracks each fluid particle (the Lagrangian approach). Traditionally, the flow field solutions resulting from the Euler equations have been accepted as being between that of solving the potential flow equations and the Navier-Stokes equations in terms of fluid dynamics sophistication.

Eulerian: See "Euler Equations."

Extended Range Operations with Twin-engine Airplanes (ETOPS): Operation of twin-engine airplanes for extended periods beyond alternate airports, as addressed by guidance material provided in AC 120-42A.

Failure ice: Aircraft ice accretion following failure of the ice protection system (IPS), or components of the system.

Finite wing: A wing having finite, or specific, span. Finite wings are affected by vortices shed at the wing tips and other aerodynamic effects, such as spanwise airflow, and are more difficult to analyze theoretically.

Forecast icing conditions: Meteorological conditions expected by a FAA-approved weather provider to be conducive to the formation of inflight icing on aircraft.

Freezing drizzle (FZDZ): Drizzle is precipitation on the ground or aloft in the form of liquid water drops that have diameters less than 0.5 mm and greater than 0.05 mm. Freezing drizzle is drizzle that exists at air temperatures less than 0 °C (supercooled), remains in liquid form, and freezes upon contact with objects on the surface or airborne.

Freezing fraction (*n*): The amount of impinging water that freezes at the point of impingement.

Freezing precipitation: Freezing precipitation is freezing rain or freezing drizzle falling through or outside of a visible cloud.

Freezing rain (FZRA): Rain is precipitation on the ground or aloft in the form of liquid water drops which have diameters greater than 0.5 mm. Freezing rain is rain that exists at air temperatures less than 0 °C (supercooled), remains in liquid form, and freezes upon contact with objects on the surface or airborne.

Glaze ice: Ice, sometimes clear and smooth, but usually containing some air pockets which result in a lumpy translucent appearance. Glaze ice results from supercooled drops/droplets striking a surface but not freezing rapidly on contact. Glaze ice is denser, harder, and sometimes more transparent than rime ice. Factors, which favor glaze formation, are those that favor slow dissipation of the heat of fusion (i.e., slight supercooling and rapid accretion). With larger accretions, the ice shape typically includes "horns" protruding from unprotected leading edge surfaces. It is the ice shape, rather than the clarity or color of the ice, which is most likely to be accurately assessed from the cockpit. The terms "clear" and "glaze" have been used for essentially the same type of ice accretion, although some reserve "clear" for thinner accretions that lack horns and conform to the airfoil.

Gridding: The process of defining elements—such as finite segments, zones, spaces, volumes, etc.—that describe the surface (body) and its external flow space for which flow conditions are calculated by a flow solver. Typically, the gridding is more dense in areas where significant changes in the flow field occur, such as in the boundary layer, high curvature surface areas, and shocks. Since gridding affects the definition of rapid flowfield changes, it also affects the precision of the flowfield solution and resulting body surface pressures. Gridding may be held fixed for a flowfield solution, or it may be adaptive, automatically changing with a time-stepping flowfield solution (according to an algorithm within the CFD code). Figure B-1 shows a gridding example.

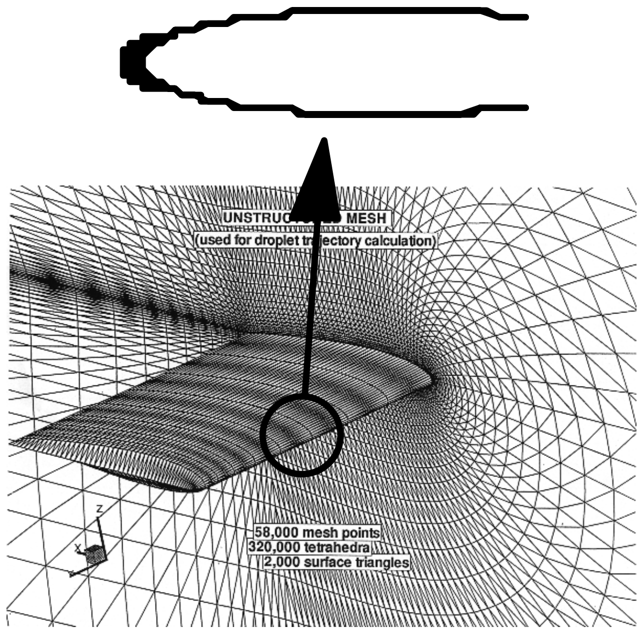

Figure B-1. Gridding of a NACA 0012 wing into a mesh of finite volumes for flow field analysis, droplet impinge computation, and ice accretion analysis [B1].

Heavy icing: A descriptor used operationally by flight crews to report to air traffic control the icing intensity being encountered. The rate of ice accumulation requires maximum use of the ice protection systems to minimize ice accretions on the airframe. A representative accretion rate for reference purposes is more than 3 inches (7.5 cm) per hour on the outer wing. Immediate exit from the conditions should be considered.

Hybrid model: Wind tunnel model truncated aft of the leading edge and designed such that the leading edge aerodynamic loading is the same as the full chord airfoil.

Ice bridging: Classic pneumatic deicing boot ice bridging occurs when a thin layer of ice is sufficiently plastic to deform to the shape of the inflated deicing boot without being fractured or shed during ensuing cycling of the deicing boot. As the deformed ice hardens and accretes additional ice, the deicing boot becomes ineffective relative to shedding the "sheath" of ice. Ice bridging may occur when a sufficient mass of supercooled water freezes during the inflated deicing boot dwell period and retains that shape after the deicing boot deflates, forming a deformed surface that continues to accrete ice and is unaffected by ensuing cycling of the deicing boot. A deicing boot ice bridge may also form when flying into increasingly colder ambient temperature conditions following a mixed-phase icing encounter at near-freezing temperatures. Ice bridging also refers to the ice "caps" or "bridges" between adjacent component surfaces, such as between unprotected leading edge surfaces of an elevator horn and the horizontal stabilizer.

Ice Evidence Probe: Device which accretes ice prior to accretion on the airframe or its components. Ice evidence probes may be used to provide visual cues.

Ice ridge: Formation of a ridge of ice typically aft of the ice protection surface usually caused by runback ice or the impingement of large droplets aft of the protection surface.

Icing in cloud: Icing occurring within visible cloud. Cloud droplets (diameter < 50 μm) will be present; freezing drizzle and/or freezing rain may or may not be present.

Icing in precipitation: Icing occurring from an encounter with freezing precipitation, that is, supercooled drops with diameters exceeding 0.05 mm, within or outside of a visible cloud.

Ice accretion limit: The location farthest aft on a body at which ice accretes. This distance can be measured either as the streamwise distance from the leading edge or as the surface distance from the stagnation point. In this document the icing limit is defined as the streamwise distance from the leading edge.

Impingement limit: The location farthest aft on a body at which water droplets impinge. This distance is usually measured as the surface length from the surface's leading edge.

Intercycle ice: Ice that accumulates on a deiced surface that exists just prior to the actuation of the deice system.

Known icing conditions: Atmospheric conditions in which the formation of ice is observed or detected in flight. (Note: Because of the variability in space and time of atmospheric conditions, the existence of a report of observed icing does not guarantee the presence or intensity of icing conditions at a later time, not can a report of no icing guarantee the absence of icing conditions at a later time.)

Known or observed or detected ice accretion: Actual ice observed visually to be on the aircraft by the flight crew or identified by on-board sensors.

Lagrangian droplet trajectory computation: A method for calculating the trajectory of water droplets in the surrounding airflow. These trajectories are typically calculated by determining the forces exerted on individual droplets and then determining the resulting motion of the droplet. The calculation proceeds by sequentially calculating forces and resulting motion as the droplet moves through the flowfield surrounding the body of interest (i.e., the wing, fuselage, engine inlet, etc.) until it either impacts on the body or passes it.

Langmuir Distribution: A family of theoretical drop size distributions based on percentages of liquid water content of each droplet size (see Appendix I for more information).

Light icing: A descriptor used operationally by flight crews to report the icing intensity being encountered to traffic control. The rate of ice accumulation requires occasional cycling of manual deicing systems to minimize ice accretions on the airframe. A representative accretion rate for reference purposes is 1/4 inch to one inch (0.6 to 2.5 cm) per hour on the outer wing. The pilot should consider exiting the condition.

Liquid water content (LWC): The mass of water contained in liquid cloud droplets within a unit volume of cloud, usually given in units of grams of water per cubic meter of air (g/m^3).

Local water catch efficiency (β): The ratio of dY to ds, where dY is the freestream distance between two droplet trajectories which intersect a surface near a point P a distance ds apart. Letting ds approach 0, the value of β at P is the derivative dY/ds.

Lower horn angle: The angle of the lower horn of a glaze ice shape, θ_{lower}, calculated with the polar direction from the wing chord plane (see Figure B-2).

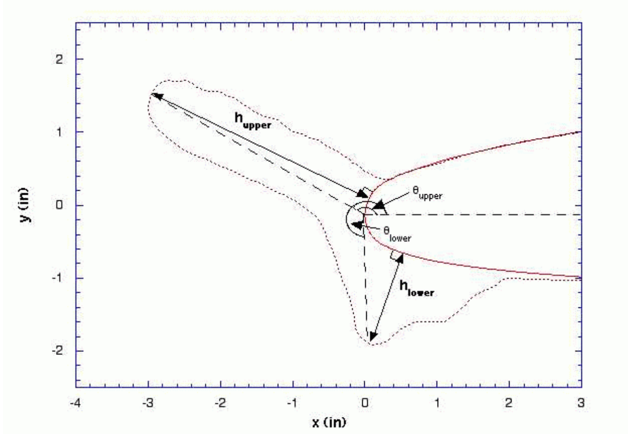

Figure B-2. Definition of horn maximum thickness angle [B1].

Ludlam Limit: The value of LWC at which the maximum rate of freezing can occur on a surface for a given combination of surface temperature, airspeed, altitude, and droplet collection efficiency.

Mean Effective Diameter (MED): The droplet diameter which divides the total water volume present in the droplet distribution in half, i.e., half the water volume will be in larger drops and half the volume in smaller drops. The value is calculated, based on an assumed droplet size distribution.

Median Volume Diameter (MVD): The droplet diameter which divides the total water volume present in the droplet distribution in half, i.e., half the water volume will be in larger drops and half the volume in smaller drops. The value is obtained by actual drop size measurements.

Mixed ice: Simultaneous appearance or a combination of rime and glaze ice characteristics. Since the clarity, color, and shape of the ice will be a mixture of rime and glaze characteristics, accurate identification of mixed ice from the cockpit may be difficult.

Mixed-phase icing conditions (Mixed conditions): Partially glaciated clouds at ambient temperature below 0° C containing a mixture of water in the phases of ice crystals and supercooled water droplets.

Moderate icing: A descriptor used operationally by flight crews to report the icing intensity being encountered to traffic control. The rate of ice accumulation requires frequent cycling of manual deicing systems to minimize ice accretions on the airframe . A representative accretion rate for reference purposes is 1 to 3 inches (2.5 to 7.5 cm) per hour on the outer wing. The pilot should consider exiting the condition as soon as possible.

Monitored surface: The surface of concern regarding ice hazard (e.g., the leading edge of a wing).

NACA inlet: A flush mounted divergent channel that creates vortices so as to suck air into the inlet. Sometimes called a submerged inlet. Developed by NACA in the late 1940s and early 1950s.

Natural icing flight tests: Flight tests that are performed in icing conditions that occur in a cloud formed by nature.

Navier-Stokes: The name given to the equations of motion for flow of a compressible, viscous fluid. A Navier-Stokes solver is an algorithm, usually in the form of a computer code that implements a numerical solution of the Navier-Stokes equations, or a simplified version of those equations. A Navier-Stokes computer code is a computational fluid-dynamics code that contains a Navier-Stokes solver and computes the flow of a compressible or incompressible, viscous fluid. Accurate determination of the motion of a fluid (air) at high

Reynolds number becomes important in the thin layer of air bounding the surface of a body. As the flow of boundary-layer transitions from laminar to turbulent and then to separation, the viscosity and compressibility of the fluid must be addressed. Solutions for the boundary layer are approximate. Those using solvers other than a full solution of the Navier-Stokes equations are further limited by the use of additional approximations used to avoid solving the full equations. These lesser solvers typically average the Reynolds stresses across the turbulent boundary layers using empirically-based approximations. The robustness of the various approximations varies, with some providing reasonable information as the intensity of the boundary-layer turbulence increases. With separated boundary-layer flow, use of the approximations is questionable. The types of flow conditions for which the empirical data are valid, therefore, limit these approximations. Full numeric solution of the Navier-Stokes equations is very difficult and costly since the five equations must be solved simultaneously for a multitude of very small finite volumes for surface area of high curvature in order to obtain good accuracy. A common practice is to limit the volume wherein the full equations are solved to the region next to the surface, and then to allow less complex flow solutions to be computed in the outer flow field in which viscosity and compressibility effects are less important. Attention must be given to the interface between the two flow solutions.

Panel code: A computational fluid-dynamics code that solves for the average flow on finite panels which define the body surface.

Potential flow: Given a flow field specified by a vector function, V, if V can be written as:

$$V = \nabla\varphi$$

for some scalar function φ, then the flow is referred to as a potential flow (and φ is called the potential function.) Inviscid, irrotational flows are potential flows. For example, potential flow equations can be used to calculate the influence of a flow phenomenon, such as a source or sink, on the velocity potential elsewhere in an irrotational, non-viscous fluid flow field. The fluid may be incompressible or compressible. Potential flow codes are the simplest of the flowfield solvers. However, the issues of the real fluid rotational flow and viscosity are not addressed. The flowfield solutions produced by the potential flow equation provide useful aerodynamic information for problems where flow rotation and viscosity effects are insignificant.

Potential icing conditions: Atmospheric icing conditions that are typically defined by airframe manufacturers relative to temperature and visible moisture that may result in aircraft ice accretion on the ground or in flight. The potential icing conditions are typically defined in the airplane flight manual or in the airplane operation manual.

Pre-activation ice: Protected surface ice accretion prior to the full effectiveness of the ice protection system.

Protected surface: A surface containing ice protection, typically located at the surface's leading edge.

Protection surface: Active surface of an ice protection system, for example, the surface of a deicing boot or thermal ice protection system.

Reference surface: The observed (directly or indirectly) surface used as a reference for the presence of ice on the monitored surface. The presence of ice on the reference surface must occur prior to—or coincidentally with—the presence of ice on the monitored surface. Examples of reference surfaces include windshield wiper posts, ice evidence probes, propeller spinner ice, and the metric sensor surface of ice detectors. The reference surface may also be the monitored surface.

Residual ice: Ice that remains on a protected surface immediately after the actuation of a deicing system.

Reynolds averaged Navier-Stokes (RANS): Denotes Navier-Stokes solver schemes that approximate the momentum changes due to turbulence (Reynolds stresses) in the boundary-layer wake through a set of equations.

Reynolds number: A dimensionless parameter that is the ratio of the inertia force to viscous force for a fluid. It is calculated according to the formula

$$Re = \rho_a VL/\mu \qquad \text{(Eqn. B-1)}$$

where V is a characteristic velocity, ρ_a is the density of the fluid, μ is the viscosity of fluid, and L is a characteristic length. Flow within the boundary layer of a surface is strongly correlated with the Reynolds number of that flow, with transition between laminar and turbulent flow in the boundary layer occurring at a critical Reynolds number for a flat plate. Also, the behavior of a separated boundary layer is characterized by Reynolds number parameters. As such, the Reynolds number is a scaling parameter for fluid flow over a surface since it controls transition and separation of the flow across the surface. To obtain similar full-scale aerodynamic parameter estimates (surface pressures) through testing of scaled models, the Reynolds number of the scaled model test should be similar to that of the full-scale aircraft in flight. Testing techniques, such as early tripping of the laminar boundary layer (that occur at low Reynolds numbers) to simulate regions of full-scale turbulent boundary-layer flow, have been used with some level of success in order to avoid the expense of testing at Reynolds numbers approaching full-scale. Typically testing at high Reynolds numbers requires the expensive use of pressure or cryogenic wind tunnels.

Rime ice: A rough, milky, opaque ice formed by the rapid freezing of supercooled drops/droplets after they strike the aircraft. The rapid freezing results in air being trapped, giving the ice its opaque appearance and making it porous and brittle. Rime ice typically accretes along the stagnation line of an airfoil and is more regular in shape and conforms more to the airfoil than glaze ice. It is the ice shape, rather than the clarity or color of the ice, which is most likely to be accurately assessed from the cockpit.

Runback ice: Ice that forms from the freezing or refreezing of water leaving protected surfaces and running back to unprotected surfaces.

Running wet: Defines heat requirements for running wet anti-icing that are based upon the maintenance of a surface temperature just above freezing, thus allowing some of the impinging water to run back and freeze aft of the heated area or off the surface.

Running wet system: Any anti-icing system that supplies only enough heat to prevent impinging water droplets from freezing on the heated surface.

Separated flow: A flow condition in which the flow is no longer attached to the surface. This phenomenon is associated with the formation of vortices and large energy losses in the flow, typically resulting in losses in lift, increased drag, and reduced control effectiveness of lifting surfaces.

Severe icing: A descriptor used operationally by flight crews to report the icing intensity being encountered to traffic control. The rate of ice accumulation is such that ice protection systems fail to remove the accumulation of ice and ice accumulates in locations not normally prone to icing, such as areas aft of protected surfaces and any other areas identified by the manufacturer. Immediate exit from the condition is necessary.

Shedding: Ice shedding is the act of separating or breaking away accreted ice from an aircraft part, initiated by passive means for any aircraft surface (e.g., by the natural aerodynamic or centrifugal forces) or by active means for protected surfaces of the aircraft (e.g., by a deicing system.

Simulated ice shapes: Ice shapes that are fabricated from wood, epoxy, or other materials by any construction technique. Simulated critical ice shapes may be tested during certification of ice protection systems. (See critical ice shapes and validation.)

Supercooled drops/droplets: Water drops/droplets that remain unfrozen at temperatures below 0 °C. Supercooled drops are found in clouds, freezing drizzle, and freezing rain in the atmosphere. These drops may impinge and freeze after contact on aircraft surfaces.

Supercooled large drops (SLD): Liquid droplets with diameters greater than 0.05 mm at temperatures less than 0 °C, i.e., freezing rain or freezing drizzle.

Total water catch efficiency (E): The total amount of water or ice that impinges on the aircraft surface. It is the integrated value of the local catch. For a two-dimensional body (for example, on an airfoil) the total catch is more conveniently expressed in terms of a unit span. An alternative (and equivalent) measurement (for a two-dimensional case) is the weighted average of the water catch efficiencies shown in equation 2.

$$E = \frac{\int \beta ds}{\int ds} \qquad \text{(Eqn. B-2)}$$

Upper horn angle: The angle of the upper horn of a glaze ice shape, θ_{upper}, calculated with the polar direction from the wing chord plane (see Figure B-2).

Validation: The process that confirms that a computer code is functioning as intended, that documentation and code version control meet the standards of the validating organization, and that predicted ice shapes match accepted experimental data in accordance with accepted validation standards within established tolerances.

Verification: The process of determining that a model implementation (i.e., a computer code) accurately represents the developer's conceptual description of the model and the code solves the equations used to describe that model.

Water catch: The mass of water captured between the upper and lower impingement limits during a specified interval of time.

Water catch efficiency (β): The ratio of actual water droplet mass flux at the surface to the water droplet mass flux in the freestream when water droplet paths are straight lines. Also known as the collection efficiency, impingement efficiency, or local impingement efficiency.

Weber number: A dimensionless parameter which is the ratio of the inertia of air to the surface tension force at the air/water interface, or more generally, the ratio of these parameters for any two fluids. For the interface of air and water, the Weber number (We) is:

$$We_l = \rho_w V_\infty^2 L / \sigma_{w/a} \qquad \text{(Eqn. B-3)}$$

where V_∞ is a characteristic velocity, ρ_w is the density of water, $\sigma_{w/a}$ is the water surface tension, and L is a characteristic length (e.g., water film thickness and drop diameter). Similar to Reynolds number, the Weber number is a scaling parameter for liquid fluids and is often encountered when liquid flow behavior or ice accretion are investigated using scaled models or when testing with scaled icing cloud droplets. Typically, holding the Reynolds number and Weber number constant for a scaled test is not possible. Resolution of this dilemma results typically in a compromise with favor given to one or the other parameter depending on the influence of the scaling parameter on the desired test results. For some cases of ice accretion, determining the scaled freestream velocity by holding model-scale and full-scale Weber number (based on leading edge water film thickness) constant and holding the freestream temperature the same has resulted in satisfying comparisons between full and model scale ice shapes. Alternatively, the model scale freestream velocity may be determined by averaging the values determined by holding the Weber and Reynolds number constant between full scale and model scale.

B.2 Acronyms and Symbols

ac	Aerodynamic center of lift (sectional)
A, A_c	Accumulation parameter, $[V(LWC)t]/[\rho_{ice}L]$

A/C	Aircraft
AC	Advisory Circular
AD	Airworthiness Directive
AFIDS	Advisory flight ice detector system
AFM	Airplane Flight Manual
AIAA	American Institute of Aeronautics and Astronautics
AGL	Above ground level
AOA	Angle-of-attack, degrees
APMS	Aerodynamic Performance Monitoring System
Appendix C	Appendix C of CFR Part 25
APU	Auxiliary power unit
ARP	Aerospace Recommended Practice
AS	Aerospace Specification
ASIC	Application specific integrated circuits
ASL	Altitude relative to sea level
BITE	Built in test equipment
b	Relative heat factor, $[LWC\beta_0\, c_{p,ws}]/h_c$
C	Celsius
c	Chord
c_d	Drag coefficient (sectional)
c_l	Lift coefficient (sectional)
c_m	Pitching-moment coefficient (sectional)
c_p	Specific heat of air
$c_{p,ws}$	Specific heat of water at the surface temperature
C_P	Pressure coefficient
CAR	Civil Air Regulations
CFD	Computational fluid dynamics
CFR	Code of Federal Regulations
d	Twice the airfoil's leading edge radius
DER	Designated Engineering Representative
DES	Detached Eddy Simulation
DNS	Direct Numerical Simulation
E	Total water catch efficiency
ECDS	Eddy current deicing system
EEDS	Electro-expulsive deicing system
EGT	Engine exhaust gas temperature
EIDI	Electro-impulse deicing system
EPR	Engine pressure ratio
Eqn.	Equation
ETOPS	Extended Range Operation with Twin-Engine Airplanes
F	Fahrenheit
FAA	Federal Aviation Administration, United States
FIDS	Flight ice detection systems
FMEA	Failure modes and effects analysis
Ft	Feet
FZDZ	Freezing drizzle
FZRA	Freezing rain
g	Gram(s)
h	Height
h	Water film thickness
h_c	Convective heat –transfer coefficient
h_G	Gas-phase mass-transfer coefficient
HE	Horizontal extent
ICTS	Ice-contaminated tailplane stall
IFC	Instrument flight conditions

IFR	Instrument flight rules
IMC	Instrument meteorological conditions
In	Inch(es)
IPS	Ice protection system
KOEL	Kind of equipment list
K	Droplet inertia parameter, $[\rho_w MVD^2 V]/[18d\mu]$, (c is sometimes used rather than d in the denominator.)
K_0	Modified droplet inertia parameter, $[\lambda/\lambda_{Stokes}]K$
k	Height of the surface roughness or protuberance
k/c	Height of the surface roughness or protuberance relative to surface chord
kt	Knots
LES	Large Eddy Simulation
LWC	Liquid water content
M	Mach number
m	Meter(s)
MED	Mean effective diameter
Microns	Micrometer
min	Minute
mm	Millimeter(s)
MMEL	Master minimum equipment list
mph	Miles per hour
MVD	Median volume diameter
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NASA-GRC	National Aeronautics and Space Administration Glenn Research Center
NLF	Natural laminar flow
Nmi	Nautical miles
OAT	Outside ambient temperature
p	Static pressure
PFIDS	Primary flight ice detector system (also known as PIIDS – primary in-flight ice detection system)
PLD	Programmable logic devices
p_w	Vapor pressure of water in the atmosphere
p_{ww}	Vapor pressure of water at the icing surface
Q_A	Heat available
Q_R	Heat required
r	Recovery factor
r.p.m.	Revolutions per minute
RANS	Reynolds-averaged Navier-Stokes
R, Re	Reynolds number
RFM	Rotorcraft flight manual
RTCA	Radio Technical Commission for Aeronautics, Inc.
SAE	Society of Automotive Engineers
s	Surface length
s, sec	Second(s)
SFAR	Special Federal Aviation Regulations
SLD	Supercooled large droplets
STC	Supplemental Type Certificate
t	Time
t_f	Freezing temperature
t_s	Surface temperature
t_{st}	Static temperature
T	Temperature
T_S	Static air temperature
TAS	True airspeed

TC	Type Certificate
TN	Technical note
V	Velocity
V_D	Dive velocity
V_{MO}	Maximum operating velocity
V_{NE}	Never exceed velocity
VFR	Visual flight rules
W	Ice accretion rate
We	Weber number
We_l	Weber number based on surface length
We_h	Weber number based on water-film thickness and water properties
$W_{detector}$	Ice accretion rate of the ice detector sensor
W_{engine}	Ice accretion rate of the engine
W_{wing}	Ice accretion rate of the wing
x/c	Longitudinal distance aft of the surface's (airfoil's) leading edge relative to the chord of the surface (airfoil)
y/c	Vertical distance above the surface's (airfoil's) reference line relative to the chord of the surface (airfoil)
2D	Two-dimensional
α	Angle-of-attack, degree(s)
β	Local water catch efficiency
β_0	Collection efficiency at the stagnation line
Λ	Leading edge sweep angle
Λ_f	Latent heat of freezing
Λ_v	Latent heat of condensation
λ	Droplet range
λ_{Stokes}	Droplet range if Stokes Law applies
n	Freezing fraction, $[c_{p,ws}/ \Lambda_f][\varphi + \theta/b]$
φ	Water droplet energy transfer parameter, $t_f - t_{st} - V^2/[2c_{p,ws}]$
°	Degree(s)
ρ_a	Density of air
ρ_i	Density of ice
ρ_w	Density of water
θ	Air-energy transfer parameter, $(t_s - t_{st} - [\mathrm{r}V^2]/[2c_{p,ws}]) + ([h_G/h_c][p_{ww}- p_w])\ \Lambda_v$
$\sigma_{w/a}$	Surface tension of water divided by surface tension of air
µ	Absolute viscosity of air
µm	Micrometer, micron
§	Section of the Federal Aviation Regulations
"	Inch(s)
[*Xn*]	Reference (where "*X*" is the letter of the appendix, if applicable, and *"n"* is the reference number)

B.3 References

B1. "Ice Accretion and Droplet Impingement Codes," SAE ARP5903.

APPENDIX C. ICE PROTECTION REGULATORY DEVELOPMENT BACKGROUND.

C.1 Large Airplanes (14 CFR Part 25)

Prior to 1953, airplanes were certificated under part 04 of the Civil Air Regulations (CAR). Section 5814 of CAR04 required that if deicing boots were installed, then positive means must be provided for the deflation of all wing boots. There were no other references to an airplane ice protection system (IPS) in part 04.

Part 4b of the CAR was codified on December 31, 1953. The requirement for positive means of deflating deicing boots was incorporated, with change, in CAR 4b § .640. CAR 4b § 690 stated that, "When an ice protection system is installed, it shall be of an approved type. If pneumatic boots are used, at least two independent sources of power and a positive means for the deflation of the boots shall be provided." CAR 4b § .351(b)(ii) provided requirements for pilot compartment vision in icing conditions. CAR 4b § .406 provided propeller-deicing requirements. CAR 4b § .461 provided induction system deicing and anti-icing requirements. CAR 4b § .612(a)(5) required that the airspeed indicating system be provided with a heated pitot tube or equivalent means of preventing malfunctioning due to icing.

Amendment 4b-2, effective August 25, 1955, introduced icing envelopes similar to the current 14 CFR part 25 Appendix C. The graphs added by Amendment 4b-2 (4b-24a, 4b-24b, 4b-24c, 4b-25a, 4b-25b, and 4b-25c) were identical in substance and format to the current Appendix C envelopes with a few exceptions. These envelopes described the liquid water content (LWC), the mean effective diameter (MED) of droplets, the temperature, and horizontal and vertical extent of the supercooled icing cloud environment. In the figures introduced by Amendment 4b-2, the units of the distances shown on the graphs were expressed in statute miles instead of nautical miles. The LWC, however, is identical between the Amendment 4b-2 figures and the current Appendix C envelopes, if the correction for the difference in value between nautical and statute miles is made. There are two significant differences between the Amendment 4b-2 envelopes and the current Appendix C. The minimum MED in the intermittent maximum conditions was 20 micrometers versus the current 15 micrometers, and the LWC-versus-distance factor chart minimum cloud horizontal extent was 1.5 statute miles versus the current 0.26 nautical miles (0.3 statute miles). The selected icing cloud envelopes were considered to be important for the design of thermal ice protection systems on large airplanes, as opposed to more complete scientific "characterizations" [C1]. A complete characterization may cover a wider range of parameters and values. Traditionally, "Continuous Maximum" conditions have been applied to airframe ice protection and "Intermittent Maximum" conditions have been applied to engine ice protection [C1]. Statistical analysis of data used to establish Figures 4b-24a and 4b-25a and subsequent data indicates that 99 percent of the data are contained within the temperature variant LWC envelopes [C2].

Amendment 4b-6, effective August 12, 1957, revised the icing envelopes to the current requirements and revised CAR § 4b.461, "Induction system deicing and anti-icing provisions." The preamble to the amendment states

> "There are included herein changes which extend the currently effective provisions governing intermittent maximum icing conditions so as to cover conditions which might be critical insofar as the turbine engine induction system is concerned. In this regard, the data are being extended in accordance with NACA Technical Note 2738 and involve a revision of Figure 4b-25a to cover drop diameters as small as 15 microns and a revision of Figure 4b-25c to cover distances down to 0.3 mile. The icing conditions prescribed in the currently effective regulations are applicable in the main to the airframe. The changes made in section 4b.461 required the turbine powerplant be subjected to the same icing conditions and required that the induction system be protected to prevent serious engine power loss. A similar requirement is incorporated with respect to certification of turbine engines by an amendment to part 13 which is being made concurrently with this amendment."

Table C-1. Chronology of 14 CFR Part 25 Icing Certification Requirements

DATE OF APPLICATION FOR AIRPLANE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
Prior to December 31, 1953	CAR Part 4	CAR § 4.5814
On or after December 31, 1953	CAR Part 4b (December 31, 1953, as amended through Amendment 4b-16)	CAR §§ 4b.351(b)(ii), 4b.406, 4b.461, 4b.612(a)(5)4b.640
On or after August 25, 1955	Amendment 4b-2	CAR § 4b.640 amended to incorporate continuous maximum and intermittent maximum icing conditions which might be reasonable anticipated during normal operations
On or after August 12, 1957	Amendment 4b-6	Revised the intermittent maximum icing conditions to include mean effective drop diameters as small as 15 µm (Figure 4b-25a). Extended the liquid water content factor, F, to distances as short as 0.3 miles. Amended CAR § .461 to require turbine powerplants and induction systems to be subjected to the continuous maximum and intermittent maximum icing conditions. (The preamble stated that the then current icing conditions requirements were mainly applicable to the airframe.)
On or after February 1, 1965	Recodification, 29 FR 18291, December 24, 1964	14 CFR 25.1419 (originally CAR § 4b.640, with minor editorial changes), § .929 (originally § 4b.406), 14 CFR § .1323(e) (originally CAR § 4b.612(a)(5)), 14 CFR 25.773(b)(1)(ii) (originally CAR § 4b.351(b)(1)(ii)), and 14 CFR 25.1093 (originally CAR § 4b.161). The CAR § 4b.351 reference to the most severe icing conditions for which approval of the airplane is desired was changed to reference the icing conditions specified in 14 CFR § 25.1419.
On or after July 29, 1965	Amendment 25-5, 30 FR 8261, June 29, 1965	14 CFR § 25.1325(b) revised to require that the calibration of the static pressure source not be changed when the airplane is exposed to Appendix C icing conditions.
On or after June 4, 1967	Amendment 25-11, 32 FR 6913, May 5, 1967	14 CFR § .1585 revised to require that the AFM include information on use of the ice protection equipment.
On or after May 8, 1970	Amendment 25-23, 35 FR 5679, April 8, 1970	14 CFR § .1419 revised to require that the effectiveness of the IPS and its components be shown by flight test of the airplane or its component in measured icing conditions. 14 CFR § 25.1309 revised to include additional requirements for certificating equipment, systems, and installations.
On or after October 31, 1974	Amendment 25-36, 39 FR 35432, October 1, 1974	Falling and blowing snow and ground ice fog requirements added to 14 CFR § 25.1093. The ground ice fog requirements were modified by Amendments 25-40, 42 FR 15034, March 17, 1977 and Amendment 25-57, 49 FR 6832, February 23, 1984, respectively.
On or after December 20, 1976	Amendment 25-38, 41 FR 55468, December 20, 1976	14 CFR § 25.1403 added to require a means to illuminate or otherwise determine to formation of ice on parts of the wing that are critical from the standpoint of ice accumulation, unless the airplane is limited from night operations.
April 12, 1978	Amendment 25-43, 43	14 CFR § 25.1326 added to require a pitot heat indication

DATE OF APPLICATION FOR AIRPLANE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
	FR 10339, March 13, 1978	system, for airplanes with a heated pitot system.
December 1, 1978	Amendment 25-46, 43 FR 50598, October 30, 1978	14 CFR § 25.1416 added to require specific standards for pneumatic deicing boots.
July 20, 1990	Amendment 25-72, 55 FR 29785, July 20, 1990	14 CFR § 25.1406 transferred to 14 CFR § 25.1419 for clarification and editorial improvement. 14 CFR § 25.1416(c) revised to allow use of the "dark cockpit" concept.

CAR Part 4b was recodified into 14 CFR Part 25, effective February 1, 1965. After recodification, with minor editorial changes, the content of CAR § 4b.640, Ice protection, became 14 CFR § 25.1419; CAR § 4b.406, Propeller deicing provisions, became 14 CFR § 25.929; CAR § 4b.612(a)(5), Airspeed indicating systems, became 14 CFR § 25.1323(e); CAR § 4b.351(b)(1)(ii), Pilot compartment view, became 14 CFR § 25.773(b)(1)(ii). The CAR § 4b.351 reference to the most severe icing conditions for which approval of the airplane is desired was changed in 14 CFR Part 25 to reference the icing conditions specified in 14 CFR § 25.1419. Section CAR § 4b.461, Induction system deicing and anti-icing provisions, became 14 CFR § 25.1093.

Amendment 25-5, 30 FR 8261, June 29, 1965 (effective July 29, 1965), revised 14 CFR § 25.1325(b) to require that the correlation between air pressure in the static pressure system and true ambient atmospheric static pressure not be changed when the airplane is exposed to the continuous and intermittent maximum icing conditions defined in Appendix C.

Amendment 25-11, 32 FR 6913, May 5, 1967 (effective June 4, 1967), revised 14 CFR § 25.1585 to require that the Airplane Flight Manual include information on the use of ice protection equipment.

Amendment 25-23, 35 FR 5679, April 8, 1970 (effective May 8, 1970), revised 14 CFR § 25.1419 to require that the effectiveness of the IPS and its components be shown by flight tests of the airplane or its components in measured natural icing conditions. Prior to this amendment, flight tests in natural icing conditions were considered as one means of compliance but were not mandatory. Amendment 25-23 also revised 14 CFR § 25.1309 to include additional requirements for certificating equipment, systems, and installations. The regulation was revised to require a comprehensive systematic failure analysis, supported by appropriate tests, to ensure that the safety objectives of the probability of occurrence decrease as the hazard of a failure increases.

Amendment 25-36, 39 FR 35432, October 1, 1974, (effective October 31, 1974), added the falling and blowing snow and ground ice for requirements to 14 CFR § 25.1093. The ground ice fog requirements were modified in 1977 and again in 1984 by Amendment 25-40, 42 FR 15034, March 17, 1977 and Amendment 25-57, 49 FR 6832, February 23, 1984, respectively.

Amendment 25-38, 41 FR 55468, December 20, 1976 (effective December 20, 1976), added 14 CFR § 25.1403 to require a means for illuminating, or otherwise determining, the formation of ice on the parts of the wings that are critical from the standpoint of ice accumulation. The requirement is not applicable if the aircraft is prohibited from flight in icing conditions at night.

Amendment 25-43, 43 FR 10339, March 13, 1978 (effective April 12, 1978), added 14 CFR § 25.1326 to require the installation of a pitot heat indication system on airplanes equipped with flight instrument pitot heating systems.

Amendment 25-46, 43 FR 50598, October 30, 1978 (effective December 1, 1978), added 14 CFR § 25.1416 to require specific standards for pneumatic deicing boots.

Amendment 25-72, 55 FR 29785, July 20, 1990 (effective July 20, 1990), transferred 14 CFR § 25.1416 to § 25.1419 for clarification and editorial improvement and deleted 14 CFR § 25.1416.

C.2 Small Airplanes (14 CFR Part 23)

Prior to 1945, airplanes were certificated under CAR part 04. Section 04.5814 required that if deicing boots were installed, they would have a positive means of deflation. There were no other references to an IPS in CAR part 04. When separate regulations (CAR part 03) were written for normal category airplanes, this requirement for positive means of deflating deicing boots was incorporated without change in CAR § 03.541. In 1949, CAR § 03.541 was renumbered as CAR § 3.712.

Ice protection was not addressed again until CAR part 03 was revised in 1962 by Amendment 3-7. This amendment added CAR § 3.772 and CAR § 3.778, which required that information be provided to the crew specifying the types of operation and the meteorological conditions to which the airplane is limited by the equipment installed. This section gave icing as a specific example of the meteorological conditions to be delineated. This change required a list of all installed equipment affecting the airplane operation limitations. The list also identified this equipment according to its operational function. This list of equipment later became known as the "Kind of Equipment List (KOEL)."

In 1964, CAR part 03 was recodified, 29 FR 17955, December 18, 1964 and 30 FR 258, January 9, 1965, into 14 CFR part 23. After recodification, CAR § 3.712 became 14 CFR § 23.1419, and CAR §§ 3.772 and 3.778(h) became 14 CFR §§ 23.1559 and 23.1583(h), respectively. In 1965, 14 CFR § 23.1325 was revised by Amendment 23-1, 30 FR 8261, June 29, 1965, to take into account the effect of icing conditions on instruments that are dependent on static pressure. In 1969, Amendment 23-7, 34 FR 13095, August 13, 1969, added the requirement in 14 CFR § 23.1093 for turbine engines to operate in 14 CFR part 25, Appendix C icing conditions. These requirements apply to all airplanes regardless of whether or not they have an IPS approved under 14 CFR § 23.1419. Amendment 23-8, 35 FR 303, January 8, 1970, added 14 CFR § 23.1529, effective February 5, 1970. In the latter part of 1968, the FAA instituted an extensive review of the airworthiness standards of 14 CFR part 23. As a result of this review, the FAA issued Amendment 23-14, 23 FR 31822, November 19, 1972, (November 1973), which made several substantive changes in the interest of safety to 14 CFR part 23. This amendment introduced a new 14 CFR § 23.929, which required engine installation ice protection and completely revised 14 CFR § 23.1419 to establish standards for IPSs. It also introduced a new 14 CFR § 23.1309, which established reliability and noninterference requirements for installed equipment and systems. These three sections are directly related, as defined in 14 CFR § 21.101, to the certification of an IPS because of the increased reliance on this system when operating the airplane in an icing environment.

Amendment 23-26, 45 FR 60154, September 11, 1980, modified 14 CFR § 23.1529 and added requirements for preparation of Instructions for Continued Airworthiness in 14 CFR part 23, Appendix G, effective October 14, 1980.

Specific standards for pneumatic deicing boots, which were contained in the former 14 CFR § 23.1419, were inadvertently omitted in Amendment 23-14, 23 FR 31822, November 19, 1972. The FAA, realizing that a specific standard for pneumatic deicing boot systems was needed, issued Amendment 23-23, 43 FR 50593, October 30, 1978, in 1978, which added 14 CFR § 23.1416, pneumatic deicing boot system. Current certification requirements are limited to those icing conditions produced by clouds containing supercooled water droplets as defined by 14 CFR part 25, Appendix C, and do not require design or proof of capability to operate in freezing rain and drizzle, snow, or mixed conditions.

In 1974, the requirements of engine operation in falling and blowing snow and ground ice fog were added to 14 CFR § 23.1093 by Amendments 23.15, 39 FR 35460, October 1, 1974. The ground ice fog requirements were modified by Amendments 23-18, 42 FR 15041, March 17, 1977 and Amendment 23-29, 49 FR 6847, February 23, 1984, respectively.

In 1987, with the creation of the commuter category, certification standards were established for airplanes that had weight, altitude, and temperature limitations for takeoff, en route, climb, and landing performance.

With the adoption of Amendment 23-41, 55 FR 43309, October 26, 1990 and 55 FR 47028, November 8, 1990 (effective November 26, 1990), 14 CFR § 23.1309 retained the existing reliability requirements adopted by Amendment 23-14, 23 FR 31822, November 19, 1972, for airplane equipment, systems, and installations that are not complex and do not perform critical functions. For those cases where the applicant finds it necessary or desirable to include complex systems and/or systems that perform critical functions, Amendment 23-41, 14 CFR § 23.1309, provides additional requirements for identifying and certificating such equipment, systems, and installations. This amendment permitted the approval of more advanced systems having the capability to perform critical functions.

In 1991, with the adoption of Amendment 23-42, 56 FR 354, January 3, 1991, (effective February 4, 1991), 14 CFR § 23.1323(e) was added to require a heated pitot tube, or an equivalent means of preventing malfunction due to icing. In addition, the requirement that a heated pitot tube be part of the system approval for flight in icing conditions was clarified. Also, 14 CFR § 23.1325(g) was added to allow airplanes that are prohibited from flight in instrument meteorological conditions (IMC) to be certificated without an alternate static air source.

In 1993, with the adoption of Amendment 23-43, 58 FR 18973, April 9, 1993, (effective May 10, 1993), 14 CFR § 23.905(e) was added to require that ice shed from the airplane not damage a pusher propeller. Sections 14 CFR 23.1093(a)(5) and (6) were added to address aircraft with fuel injected engines. Section 14 CFR 23.1093(a)(6) specified ice protection requirements for fuel injection system designs with and without metering components on which impact ice may accumulate. Also, 14 CFR § 23.1307(c) was added to require the airplane type design to include all of the equipment necessary for operation in accordance with the limitations required by 14 CFR § 23.1559. 14 CFR § 23.1419 was revised to do the following: to continue the current minimum ice protection requirements that have been found necessary for safe operation in icing conditions, to provide specific test requirements, to clarify the requirements for information that must be provided to the pilot, and to allow approval of equivalent components that have been previously tested and approved, and that have demonstrated satisfactory service if the installations are similar.

In 1993, with the adoption of Amendment 23-45, 58 FR 42165, August 6, 1993, (effective September 7, 1993), the following sections were added: (1) 14 CFR § 23.773(b) to provide requirements for the pilot compartment view to address the environment expected in all the operations requested for certification; (2) 14 CFR § 23.775(f) to clarify the criteria for determining the cleared windshield area that is necessary to ensure safe operation in icing conditions; (3) 14 CFR § 23.775(g) to require that a single failure of a transparency heating system not adversely affect the integrity of the airplane cabin nor increase the danger of fire; and (4) 14 CFR § 23.1525 was revised to require the establishment and inclusion of the kinds of operations authorized in the Airplane Flight Manual (AFM) as specified by 14 CFR § 23.1583(h).

In 1996, with the adoption of Amendment 23-49, 61 FR 5168, February 9, 1996, (effective February 9, 1996), 14 CFR § 23.1325(g) was revised by exempting airplanes that are prohibited from flight in instrument meteorological or icing conditions from the requirements of 14 CFR § 23.1325(b)(3). Also, 14 CFR § 23.1326 was added to require the installation of a pitot tube heat-indicating system on those airplanes required to be equipped with a heated pitot tube. Airplanes that are approved for instrument flight, or for flight in icing conditions, would be required to be equipped with a heated pitot tube and a heated pitot tube indicator by this amendment.

Table C-2. Chronology of 14 CFR Part 23 Icing Certification Requirements

DATE OF APPLICATION FOR AIRPLANE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
Prior to February 1, 1965	Part 3 of the CAR, (May 15, 1956, as amended through Amendment 3-8)	§§ 3.85(a) and (c), 3.85a(a) and (c), 3.382, 3.383, 3.446, 3.575, (including note following (b)), 3.652, 3.652-1, 3.665, 3.666, 3.681, 3.682, 3.685, 3.686, 3.687, 3.690, 3.691, 3.692, 3.712, 3.725, 3.758, 3.770, 3.772, 3.777, 3.778, and 3.779
On or after February 1, 1965	Recodification, 29 FR 17955, December 18, 1964 and 30 FR 258, January 9, 1965.	§§ 23.65, 23.75, 23.77, 23.773, 23.775, 23.1301, 23.1351, 23.1357, 23.1437, 23.1541, 23.1559(b), 23.1583(h), 23.1585, and 23.1419 (boot requirement before Amendment 23-14)
On or after July 29, 1965	Amendment 23-1, 30 FR 8261, June 29, 1965	Add § 23.1325 to the above part 23 requirements.
On or after September 14, 1969	Amendment 23-7, 34 FR 13095, August 13, 1969	Added the requirement in 14 CFR § 23.1093 for turbine engines to operate in 14 CFR part 25, Appendix C icing conditions.
On or after February 5, 1970	Amendment 23-8, 35 FR 303, January 8, 1970	Add § 23.1529 to the above part 23 requirements.
On or after December 20, 1973	Amendment 23-14, 33 FR 31822, November 19, 1973.	Add §§ 23.853(d), 23.929 and 23.903(c) to the above part 23 requirements.
On or after October 31, 1974	Amendment 23-15, 39 FR 35460, October 1, 1974	Falling and blowing snow and ground ice fog requirements added to 14 CFR § 23.1093. The ground ice fog requirements were modified by Amendments 23-18, 42 FR 15041, March 17, 1977 and Amendment 23-29, 49 FR 6847, February 23, 1984, respectively.
On September 1, 1977	Amendment 23-20, 42 FR 36969, July 18, 1977	Add §§ 23.1327 and 23.1547 to the above part 23 requirements.
On or after December 1, 1978	Amendment 23-23, 43 FR 50593, October 30, 1978	Add §§ 23.863, and 23.1416 (in lieu of the boot requirement of § 23.1419 before Amendment 23-14) to the above part 23 requirements.
On or after October 14, 1980	Amendment 23-26, 45 FR 60154, September 11, 1980	Modified 14 CFR § 23.159 and added requirements for preparation of Instructions for Continued Airworthiness as 14 CFR part 23, Appendix G.
On or after February 17, 1987	Amendment 23-34, 52 FR 1833, January 15, 1987	For commuter category airplanes, add §§ 23.67(e)(2), 23.67(e)(3), 23.997(e), and 23.1199(b) to the above part 23 requirements.
On or after February 4, 1991	Amendment 23-42, 56 FR 354, January 3, 1991	Add §§ 23.1323(e) and 23.1325(g) to the above part 23 requirements.
On or after May 10, 1993	Amendment 23-43, 58 FR 18973, April 9, 1993	Add §§ 23.905(e), 23.1093(a)(6), and 23.1307(c) to the above part 23 requirements.
On or after September 7, 1993	Amendment 23-45, 58 FR 42165, August 6, 1993	Add §§ 23.773(b), 23.775(f), 23.775(g), and 23.1525 to the above part 23 requirements.
On or after October 14, 1980	Amendment 23-26, 45 FR 60154, September 11, 1980	Modified 14 CFR § 23.159 and added requirements for preparation of Instructions for Continued Airworthiness as 14 CFR part 23, Appendix G.

Because of the large fleet of small airplanes that have been certificated under the requirements of earlier regulations, the applicability of later regulations to previously-approved ice protection provisions may vary as those aircraft are modified.

By their adoption in Amendment 23-14, which shows their requirements are directly related, 14 CFR §§ 23.929, 23.1309, and 23.1419 are applicable to a 14 CFR part 23 airplane icing certification program regardless of the certification basis for the basic airplane; however, for those airplanes certificated in accordance with part 3 of the CAR and part 23 through Amendment 23-13, the application of these sections may be limited to the equipment being used for ice protection. Some systems that were previously approved on the airplane may need to be modified to improve their reliability when those systems are utilized as part of that airplane's icing approval.

With the adoption of Amendment 23-43, 14 CFR § 23.1419 was revised to do the following: to continue the current minimum ice protection requirements that have been found necessary for safe operation in icing conditions, to provide specific test requirements, to clarify the requirements for information that must be provided to the pilot, and to allow approval of equivalent components that have been previously tested and approved, and that have demonstrated satisfactory service if the installations are similar.

In addition to the previously mentioned requirements (14 CFR §§ 23.929, 23.1309, and 23.1419), Table C2 lists the sections that should be applied depending upon the IPS design and the original certification basis of the airplane. Many of the requirements listed in Table C-2 are also applicable, even without approval for flight into known icing.

C.3 Engines

Until the late 1950s, the only icing requirements relating to engines were carburetor icing requirements that were applied to reciprocating engines and then to induction system icing. During the late 1950s, with the introduction of turbine engines, CAR were introduced for turbine engines and fuel and induction systems icing. Amendment 4b-6, effective August 12, 1957, revised CAR § 4b.461, "Induction system deicing and anti-icing provisions." The preamble to the amendment states

> "There are included herein changes which extend the currently effective provisions governing intermittent maximum icing conditions so as to cover conditions which might be critical insofar as the turbine engine induction system is concerned. In this regard, the data are being extended in accordance with NACA Technical Note 2738 and involve a revision of Figure 4b-25a to cover drop diameters as small as 15 microns and a revision of Figure 4b-25c to cover distances down to 0.3 miles. The changes made in section 4b.461 required that the turbine powerplant be subjected to the same icing conditions as the airframe and that the induction system be protected to prevent serious engine power loss. A similar requirement is incorporated with respect to certification of turbine engines by an amendment to part 13 which is being made concurrently with this amendment."

Later, during 1965, the Federal Aviation Regulations (FAR) were codified from the CAR, and the turbine engines icing requirements were placed in 14 CFR 33.66, 33.67, and 33.89.

The induction system icing requirements of 14 CFR parts 33, 23, and 25 are intended to provide protection for planned or inadvertent flight into icing conditions with no adverse effect on engine operation or serious loss of power or thrust. Propulsion systems certified under these requirements (14 CFR parts 23 and 25 § .1093, and § 33.68) and operated in accordance with the AFM have demonstrated safe operation when exposed to natural icing environments. 14 CFR § 33.68 was introduced in Amendment 33-6, 39 FR 35463, October 1, 1974. Requirements were extracted from 33.67, fuel and induction system requirements. Notwithstanding the fact that 14 CFR 33.68 is entitled "induction system icing," turbine engines do not typically include the "induction system" (e.g., inlet, or other air delivery ducting) in the engine Type Design. Therefore, turbine engine 14 CFR 33.68 icing issues are predominantly "internal" to the engine (including the spinner, fan blades, compressor stators and blades, etc.) and typically reside in the category of unprotected surfaces, whereas the induction systems ordinarily include a protection technology (hot air, electrical heating, deicing boots, etc.). Guidance material is contained in AC 33-2B for engine and engine installation approvals.

The suggested test conditions called out in these ACs are intended to be standardized engine icing certification test conditions. These standard conditions in conjunction with any design-specific critical points should be used together with any additional conditions that the Administrator determines are critical. These standard test conditions have been determined, through more than 30 years of certification experience to provide an adequate and consistent basis for engine icing certification and have resulted in good service experience. They are intended to address the potential myriad of engine power conditions, aircraft flight conditions, and environmental conditions. Service experience, now in the hundreds of millions of hours, has also shown a long success record when using these test points to cover unknown environmental or operational factors.

An icing encounter, including a prolonged encounter, should not be of consequence to the crew and it should not have results which are not in compliance with any other 14 CFR Part 33 requirement. The engine should have sufficient durability to operate through prolonged or repeated environmental encounters, such as icing, without special operational or maintenance intervention. Operational procedures to assist ice shedding, such as throttle manipulation, should not be relied upon or be required to comply with inflight icing requirements specified in 14 CFR parts 23, 25, and 33. It is acceptable to provide engine throttle manipulation (e.g., power run-ups to shed ice) instructions to shed accumulated ice during ground operations. These instructions will be used as a recommendation for in-service ground operation, although they would be mandatory if they were utilized during the ground icing compliance demonstration of 14 CFR §§ 33.68(b), 23.1093(b)(2), and 25.1093(b)(2).

Table C-3. Chronology of 14 CFR Part 33 Engine Icing Certification Requirements

DATE OF APPLICATION FOR ENGINE TYPE CERTIFICATION	CAR/TITLE STATUS	ICING CERTIFICATION REQUIREMENTS
Prior to August 12, 1957	Part 13 of the CAR, (May 15, 1956, as amended through Amendment 13-1)	§§ 13.110(b), 13.155 (Reciprocating engines and fuel induction systems only)
On or after August 12, 1957	Part 13 of the CAR, (May 15, 1956, as amended through Amendment 13-5)	§§ 13.110(b), 13.155 (Recip. Engines) §§ 13.210(b), (c) and (e), 13.255 (Turbine Engines)
On or after February 1, 1965	Recodification, 29 FR 7453, June 10, 1964	§§ 33.35, 33.51 (Recip. Engines) §§ 33.66, 33.67, 33.89 (Turbine Engines)
On or after October 1, 1974	Amendment 33-6, 39 FR 35463, October 1, 1974	Replace § 33.67 with § 33.68

Compliance with the requirements of §14 CFR 33.68 includes identifying, through design analysis, the critical operating points for icing within the declared operating envelope of the engine (throughout its flight power range, including idling). The design analysis, also known as critical point analysis, should include a range of possible combinations of icing conditions. 14 CFR part 25, Appendix C, aircraft speed range; engine powers as defined by the engine manufacturer; and prolonged operation in icing (e.g., inflight hold pattern); or repeated icing encounters should be considered in setting this range. The design analysis should be validated by empirical test data. This analysis should consider critical ice accretion conditions (both environmental and engine-operational), accretion locations, as well as the most critical engine operating conditions for the shedding and ingestion of ice. Often the critical-point analysis is supplemented with development test data (e.g., wet and dry testing with thermocouple components). The methodology used to calculate ice accretions should account for pertinent aerodynamic effects such as water ingestion into fan inlet and core inlet (scoop factors), water impingement rates for critical surfaces, forward aircraft air speed effects, engine configuration effects such as inter-compressor bleed, and altitude effects such as bypass ratio effects. This should be in conjunction with an energy balance of critical engine surfaces, for example, latent heat and heat of fusion effects, metal-to-ice heat transfer effects, and ice insulating effects. For anti-iced parts, the design point should be determined from energy balance calculations of required heat loads encompassing the range of possible combinations of icing condition and engine power. In instances of low freezing fraction in glaze ice conditions, additional complexities arise from assessing the effects of non-aerodynamic ice formations and their shedding. FAA Report No. FAA-RD-77-76, Engineering Summary of Powerplant Icing Technical Data, provides additional guidance on performing a design icing analysis. Table C-3 lists the sections that should be applied.

C.4 Rotorcraft

In CAR part 6, the only icing requirement for Normal Category rotorcraft was related to carburetor preheat, CAR § 6.462 "Induction system deicing and anti-icing provisions." This requirement was carried over to 14 CFR §27.1093. Approval of other ice protection provisions for a type of operation in icing conditions, CAR § 6.718, was not addressed prior to the 1964 recodification of the regulations.

The earlier Transport Categories Rotorcraft airworthiness requirements, CAR 7 § .392, did address approval of ice protection provisions for icing conditions applicable to the operating limitations of the design. This CAR part 7 requirement was carried over into 14 CFR 29 § .877 and now as 14 CFR § .1419. CAR part 7 did address pilot compartment vision, requiring "sufficiently extensive view to permit safe operation" in the most severe icing conditions in which operation of the rotorcraft is approved. The pilot compartment requirement was carried over into 14 CFR 29 § .773. Engine air induction and engine air induction system screens ice protection provisions, CAR §§ 7 .461 and .464, were carried over into 14 CFR 29 §§ .1093 and .1105.

C.5 References

C1. **"Recommended Values of Meteorological Factors to be Considered in the Design of Aircraft Ice-Prevention Equipment,"** NACA Technical Note 1855 (1949), NASA/Ames Research Center, Moffett Field, California 94035.

C2. **"Review of Icing Criteria,"** Lewis, William, <u>Aircraft Ice Protection, Report of Symposium, April 28-30, 1969.</u>